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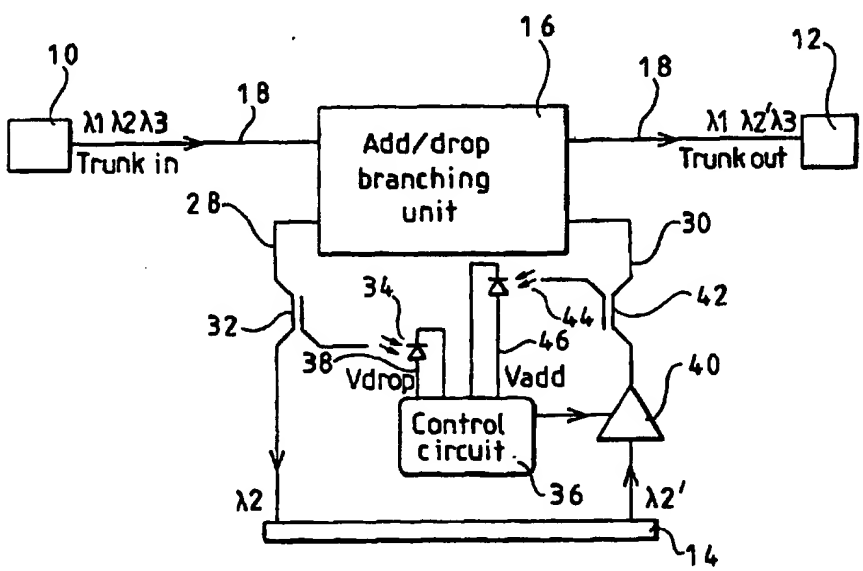

(57) Abstract

An optical wavelength division multiplexing system, method and branching unit. The arrangement drops one, or more than one, predetermined wavelength signal (λ_2) from a trunk (18) onto a branch and adds signals (λ_2') at the predetermined wavelength, or at predetermined different wavelengths from the branch out the trunk. A sensor (34) senses the level of the signal(s) dropped and a controller (36), which responds to the control signal, adjusts the level of the add signal(s) (λ_2') to an optimum level for adding to the trunk (18).

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IMPROVEMENTS IN OR RELATING TO OPTICAL ADD/DROP WAVELENGTH DIVISION MULTIPLEX SYSTEMS

This invention relates to add/drop wavelength division multiplexing systems and more particularly to the control of the level of added signals. The invention has particular application in underwater cable systems employing fibre cables.

Wavelength division multiplexing, termed WDM, (discussed in, for example, Hill, British Telecom Technology Journal 6(3): 24-31) is a technique of considerable benefit in optimising transmission of signals through fibre optic networks. In wavelength division multiplexing, traffic signals to be sent out by a station are modulated on to a number of carrier signals at different predetermined carrier wavelengths. Each predetermined carrier wavelength is allocated according to the identities of the send station and of the intended receive station. Predetermined carrier wavelengths will be spaced sufficiently far apart in wavelengths that they can be discriminated from each other by components of the fibre optic system, but in many networks will need to be grouped sufficiently closely that all carrier wavelengths can be amplified satisfactorily by the same amplifier in a repeater (or in unrepeated systems, to be carried long distances without significant loss). The carrying capacity of a single fibre is enhanced by WDM - rather than carrying a single signal, the fibre is simultaneously carrying several signals, each of a different wavelength.

Most such transmission networks have a number of nodes at which one or more branches form away from a main trunk or ring. Typically, at these nodes one or more carrier wavelengths are dropped down one fibre of the branch and one or more carrier wavelengths (which may be the same as, or

different from, those dropped from the trunk or ring) are added to the trunk or ring from another fibre of the branch. The component which performs such a function is an Add/Drop Multiplexer (ADM).

WDM is particularly well adapted to efficient routing of signals between send and receive stations. As different signals have different carrier wavelengths, optical components can be used to route signals appropriately by directing them according to the carrier wavelength of the signal.

This can be done in an active manner, by splitting the signal into its component carrier wavelengths with a prism or similar component, and actively processing and routing the split signals to desired outputs. This solution is appropriate for use in an integrated device: a basic design for a multiplexer of this type is discussed in Dragone et al in IEEE Photonics Technology Letters 3(10):896-899, and designs employing arrayed-waveguide gratings are disclosed for an ADM in Okamoto et al in Electronics Letters 31(9):723-4 and for an optical splitter/router in Inoue et al in Electronic Letters 31(9):726-7.

Alternatively, passive optical components can be used which respond differently to different carrier wavelengths. This enables passive network to be constructed.

The use of wavelength division multiplexing branching units (WDM BU) in optically amplified networks present new problems for the control and management of the networks. One of the problems is matching of the optical level of the added channel to the other channels passing along the trunk. I present a simple automatic scheme for controlling the power of the added channel, so that it is added back into the system at the optimum level.

To equalise the performance of the different channels in a WDM system, pre-emphasis is applied to the powers of the channels. This may be effected in the manner described in A.R. Chraplyvy, J.A. Nagel, R.W. Tkach, "Equalisation in Amplified WDM Lightwave Transmission Systems", IEEE Photonics Tech. Lett., Vol. 4, pp. 920-922, 1992. This results in a system dependent power profile for the different channels. The dropping of channels from the line, and subsequent adding in of new channels (at the same wavelengths or even at different wavelengths) requires ideally that the level of the added channel(s) is such that it matches the trunk channels which pass straight through the BU.

Accordingly, the present invention seeks to provide for the adding of wavelengths to the trunk of an optical fibre communication system at an optimum level.

According to one aspect of the invention there is provided an optical wavelength division multiplexing add/drop branching unit for dropping one, or more than one, predetermined wavelength signals from a trunk onto a branch and for adding signals at said predetermined wavelength(s), or at predetermined different wavelength(s), from the branch onto the trunk, characterised in sensing means for providing a control signal related to the level of the signal(s) dropped and control means responsive to the control signal to adjust the level of the add signal(s) to an optimum level for adding to the trunk.

According to another aspect of the invention there is provided a method of operating an optical fibre wavelength division multiplex communication system in which multiple wavelength signals are transmitted and received along a trunk cable, one, or more than one, predetermined wavelengths are dropped onto a branch to a receive/transmit

station and one, or more than one, of said predetermined wavelengths, or predetermined different wavelength(s) is/are added to the trunk, characterised in that the level of the dropped wavelength(s) is/are sensed and used to control the level of the added wavelength(s) which are thereby introduced onto the trunk at an optimum level.

In order that the invention and its various other preferred features may be understood more easily, some embodiments thereof will now be described, by way of example only, with reference to the drawings, in which:-

Figure 1 is a schematic block diagram to illustrate the basic concept of the invention in a simple single wavelength drop system,

Figure 2 illustrates schematically one suitable add/drop branching unit suitable for use in the system of Figure 1,

Figure 3 is a block schematic diagram providing further detail of a control circuit and laser pump optical amplifier shown in Figure 1,

Figure 4 is a block schematic circuit diagram illustrating a limited control circuit suitable for use in the arrangement of Figure 3,

Figure 5 is a block schematic circuit diagram illustrating an add level adjust circuit suitable for use in the arrangement of Figure 3,

Figure 6 is a block schematic diagram illustrating a supervisory function suitable for use in a system in which a plurality of wavelengths are dropped and added at a branch, and Figure 7 is a block schematic diagram illustrating the use of a supervisory signal to attenuate an

add signal.

The arrangement of Figure 1 illustrates, for simplicity of explanation, a basic add/drop WDM system in which a single branch is employed along an optical fibre trunk cable and in which three different wavelengths λ_1, λ_2, λ_3 are employed each for carrying signals specific to one of two terminals 10, 12, located one at each end of the trunk and one to a terminal 14 at the end of a cable branch. An add/drop branching unit 16 is connected in the optical fibre trunk cable and is arranged to permit passage of wavelengths λ_1 & λ_3 between terminals 10 and 12 but to direct wavelengths λ_2 to the branch terminal 14.

A suitable add/drop branching unit is illustrated in Figure 2 and employs three port circulators 20, 22 and a Bragg reflection filter 24. A transmission at input 26 with carrier wavelengths λ_1, λ_2, λ_3 enters first circulator 20. The whole transmission passes out through the second port of the circulator to filter 24, which reflects the λ_2 component but allows the λ_1 and λ_3 components to pass. The λ_2 component thus proceeds to the second port of the first circulator 20, passes through to the next port in sequence, the third port, and thus passes out along drop branch A. The added signal at carrier wavelength λ_2' from add branch 30 enters the first port of the second circulator 22 and exits through the second port towards filter 24, which reflects it. The added λ_2' signal thus joins the λ_1 and λ_3 signals of the main transmission in entering the second port of second circulator 22, and all three carrier wavelengths thus pass out through the third port of the second circulator 22. Such an ADM is effective for adding and dropping signals at a given wavelength to a single line, but is not sufficient to enable efficient routing in a more complex network or for adding wavelengths different to the wavelength dropped. It is to be understood that any suitable add/drop branching units can be employed for example any of those disclosed in

our copending PCT application No. filed the same day as the present application and entitled "Add/drop Multiplexer" the whole contents of the specification of which is hereby incorporated by reference.

Referring now again to Figure 1 the carrier wavelength λ_2 on the drop branch A is routed to branch terminal 14. An optical tap 32 couples a portion of carrier wavelength λ_2 from the drop branch A to an optical sensor 34, e.g. a PIN diode as illustrated, which forms a first sensor for a control circuit 36 and provides a voltage V drop at 38.

The branch terminal 14 provides an add signal λ_2' at the same wavelength as the drop signal and this is routed via a variable gain optical amplifier 40 through an optical tap 42 to the add branch 30 of the add/drop multiplexer 16. The tap 42 couples a portion of the add wavelength λ_2' to an optical sensor 44, e.g. a PIN diode as illustrated, which forms a second sensor for the control circuit 36 and provides a voltage V_{add} at 46. The control circuit 36 compares the voltages V_{add} and V_{drop} and provides a control signal to control the gain of optical amplifier 40 in dependence upon the relative levels of the signals at 28 and 30 to optimise the level of the add signal for coupling to the trunk.

Ideally the level of the added channel (at 30) would be matched to the level of the dropped channel (at 28), if the loss from the trunk-in to the drop is equal to the loss of the add to the trunk out. This would result in the same level being added to the trunk, at λ_2' in this case, as is being dropped from the trunk. Since the losses of the two taps are known (measured on build), the powers measured by the photodiodes 34, 44 can be used to asses the optical powers at 28 and 30. The control circuit allows balance of these powers by adjusting the pump level (output level) of

the optical amplifier on the add fibre.

In practice the add/drop multiplexer has a finite loss (e.g. L_{ADM} dB) and by the set up of the control circuit, the level at 30 can be set to L_A - L_{ADM} dNm (where L_A is the power at 28) to add the new wavelength in at the level that the dropped channel would have been at the output of the add/drop multiplexer.

Referring now to the drawing of Figure 3, the control circuit 36 and optical amplifier 40 are shown in more detail. The drop voltage V_{drop} at 38 is input to a limited control circuit 39 this circuit is intended to provide a low input threshold for the drop signal so that if the drop wavelength is removed the amplifier does not turn itself up to full level on noise, but that it is inhibited to a lower level. This circuit is described with reference to Figure 4 from which it can be seen that the voltage V_{drop} 38 forms one input for an operational amplifier 48. A series resistor network is formed by a first resistor 50 a second resistor 52, a third resistor 54 and a fourth resistor 56 connected in series between different d.c. voltage supply lines 58, 60. The other input of the operational amplifier 48 is coupled to the junction between the second and third resistors and the output of the operational amplifier is coupled to the junction between the first and second resistors via a resistor 62. The junction between the third and fourth resistors provides a limited control voltage V_{LIM} at 64 which forms an input to a comparator 66 illustrated in Figure 3.

The sensor 34 is connected in series with a resistor 68 between d.c. supply terminals 58, 60 and the voltage V_{drop} is developed across the resistor 68. The voltage V_{drop} varies proportionally to the total optical power detected by the sensor 34. The output of the operational amplifier 48 follows V_{drop} and is capable of large voltage swings which are

limited by voltages provided by the series resistor network. The value of resistor 62 influences the available voltage output swing and by making this resistor variable, the swing can be adjusted. The value of the resistor 50 influences the upper limit of voltage output and by making this resistor variable, the upper voltage limit can be adjusted. For a single channel system, as so far described, the upper level adjustment is not required and the lower limit can be set to provide a low input threshold for the operational amplifier 48. This stops the optical amplifier from being turned full on when there is no drop channel wavelength.

Referring now to Figure 3 the add level voltage V add at 6 is routed via a level adjust circuit 70 to the other input of the comparator 66. In a simple single drop wavelength system this might be a manual adjustment during build but in a system where more than one wavelength is dropped and added a more complex arrangement for compensating for the absence of one or more dropped wavelengths after the system has been installed is advisable as will be described later in connection with Figure 5.

Referring again to Figure 3 the optical amplifier 40 is shown as comprising a pump laser amplifier 72 having its input 74 coupled to the branch terminal 14 for receiving the add wavelength λ_2'. The output of the amplifier 72 is coupled to the add branch 30. An output voltage V_{out} out from the comparator 66 forms the input to the gate electrode of a field effect transistor 78 controls the current flowing through the transistor to a laser pump 80. Thus the pump drive current is changed to keep the level of V_{adj} equal to V_{LIM}.

Although most of the preceding description has been in relation to a simple system in which a single wavelength is dropped and added at a branch more complex systems within the ambit of this invention can drop and add a plurality of

wavelengths at a branch. A difficulty which arises in such a system is that the voltage V_{drop} is related to the aggregate level of the detected dropped wavelengths and the absence of one or more of the wavelengths suggests that the signal level to be added needs to be reduced. This situation can be corrected by employing an add level adjust circuit 70 in the form of an attenuator as illustrated in Figure 5. The voltage V_{add} at 46, which relates to the sensed add signal, forms one input for an operational amplifier 80 and the output is coupled via an attenuation network comprising diodes D1 to D5 and resistors R1 to R8. The diodes D2 to D4 are controlled from a two state logic level controller 82. Applying logic high or logic low at combinations of A, B & C select particular resistor combinations and vary the output voltage V_{adj} which is fed to the comparator 66 (Figure 3). The attenuator is controlled by supervisory signals sent from a remote terminal, upon detection of the absence of signals at particular wavelengths, as will now be described in connection with Figure 6 & 7.

Figure 6 shows a remote terminal 90 including a transmission data generator 92 coupled with an optical transmitter 94 to an optical modulator 96 which feeds the trunk 18. Data received on an incoming trunk fibre 98 or fibres is coupled to a detector 100 which is arranged to detect the presence of specific wavelengths. This can be done in any suitable manner such as will be clear to a person skilled in the art for example the different wavelengths can be separated by filtering with Bragg gratings and individually detected by a photosensitive diode. The detected information is fed to a supervisory encoder 101 which generates a specific digital code indicative of the presence or absence of each particular wavelength and this code is fed to the optical modulator for transmission. An input command controller 102 is effective to initiate transmission of supervisory signals by initiating the supervisory encoder to send to e.g. a set add

level to minimum digital code. The frequency of the supervisory system is arranged to be lower than the frequency of the transmitted data.

Referring now to Figure 7 at the branching unit a small amount of the light passing through the BU is tapped off via a 20:1 tap coupler 104 (the ratio is not critical, this in practice would be the same type of coupler as 32 & 42 in (Figure 1). The light is incident on an optical sensor 106 which converts the signal to an electrical signal H.

The electrical signal is then filtered using a narrow bandpass filter 108 centred on the supervisory frequency. This is then decoded by decoder 110 and the command words acted upon by the 2 state logic level controller 82 also shown in Figure 5.

It would also be possible to have a limited adjustment on the power at 30 relative to 28 (Figure 1) via the amplifier supervisory scheme. This would allow the add level to be adjusted up and down relative to the drop level at 28, in the event that the transmission distance from primary node 1 to 28 is very much less (or more) than the distance from 30 to primary node 2. This would allow for very fine adjustment of the pre-emphasis to maintain the optimum independence of the location of the BU within the system.

A further advantage of this system is that the accuracy of setting of the output power of the secondary node terminal is much reduced. So long as the level does not get too low, and degrade the optical signal to noise ratio, then the output power controlled amplifier will maintain the correct output independent of the input level from the secondary node transmitter. This also benefits system security.

Some possible advantages of systems constructed in accordance with the invention or its refinements are -

1. Level of add channel automatically adjusted to be equal to level of drop channel.

2. Optimum system pre-emphasis levels maintained.

3. Simple BU design - Output amplifier automatically adjusts independent of system application.

4. Simplicity of adjustment of pre-emphasis. Only done at Primary nodes of network.

5. Reduced constraints on the accuracy of the secondary node output power.

6. Power offset relative to drop power available for optimum adjustment in asymmetric system topographies.

CLAIMS:

1. An optical wavelength division multiplexing add/drop branching unit for dropping one, or more than one, predetermined wavelength signals (λ_2) from a trunk (18) onto a branch and for adding signals (λ_2') at said predetermined wavelength(s), or at predetermined different wavelength(s), from the branch onto the trunk (18), characterised in sensing means (34) for providing a control signal related to the level of the signal(s) (λ_2) dropped and control means (32) responsive to the control signal to adjust the level of the add signal(s) (λ_2') to an optimum level for adding to the trunk.

2. A branching unit as claimed in claim 1 or 2, characterised in that the sensing means (34) comprises an optical to electrical transducer which provides an electrical signal V_{drop} which is a function of light signals sensed.

3. A branching unit as claimed in claim 2, characterised in that additional sensing means (44) similar to said sensing means provides an electrical signal (V_{add}) the level of which is a function of light signals sensed from the add signal, wherein the control means (36) includes a comparator (66) which compares the level of the add signal with the level of the signal dropped and the comparison signal (V_{out}) is used to adjust the level of the add signal to an optimum level for adding to the trunk.

4. A branching unit as claimed in claim 3, characterised in that the, or each, sensing means (34, 44) is coupled to a drop or add fibre of the branch via an optical tap (32,42).

5. A branching unit as claimed in claims 3 or 4, characterised in that each sensing means (34, 44) provides a variable voltage (V_{drop}, V_{add}) which forms the electrical

signal (V_{out}) which is a function of light signals sensed and the comparator (66) is a voltage comparator.

6. A branching unit as claimed in claim 5, characterised in that the voltage comparator (66) is an operational amplifier.

7. A branching unit as claimed in claim 5 or 6, characterised in that each sensing means (34, 44) comprises a series arrangement of a PIN diode and a resistor coupled between different d.c. voltage supply lines (58, 60) and the voltage developed across the resistor forms the electrical signal.

8. A branching unit as claimed in claim 5, 6 or 7, characterised in that a threshold circuit is provided between said sensing means (34) and the comparator (66), which threshold circuit is effective to prevent response of the comparator until a predetermined level of drop signal is sensed.

9. A branching unit as claimed in claim 8, characterised in that the threshold circuit comprises an operational amplifier (48) and a series resistor network having four resistors (50, 52, 54, 56) which network is coupled between different d.c. voltage supply lines (58, 60), one input of the operational amplifier is coupled to the sensing means (34) to receive the voltage (V_{drop}) which is a function of the drop signal, the output of the operational amplifier is coupled to the junction between first (50) and second (52) resistors in the series network, the other input of the operational amplifier is coupled to the junction between the second (52) and third resistors (54) in the network and the junction between the third (54) and fourth resistors (56) in the network forms the threshold limited output voltage (V_{LIM}).

10. A branching unit as claimed in claim 9, characterised in that a variable resistor (62) is provided in the coupling between the output of the operational amplifier and the junction between first (50) and second (52) resistors in the network, which variable resistor permits adjustment of the voltage swing of the threshold limited output (V_{LIM}).

11. A branching unit as claimed in claim 9 or 10, characterised in that the first resistor (50) of the network is a variable resistor which permits adjustment of the upper voltage limit of the threshold limited output (V_{LIM}).

12. A branching unit as claimed in any one of the preceding claims, characterised in that the add signal is routed to the trunk via an optical amplifier (40) which is responsive to the control means (36) to adjust the level of the add signal.

13. A branching unit as claimed in any one of Claims 5 to 12, characterised in that there is provided an attenuator (70) for adjusting the level of the electrical signal which is a function of the add signal in response to an optical supervisory signal provided from a terminal (90) along the trunk where the absence of said, or any of said, predetermined wavelength(s), or predetermined different wavelength(s), is detected.

14. A branching unit as claimed in claim 13, characterised in that the attenuator (70) comprises a two state logic level device (82) in which resistors (R_4, R_6) are selectively switched into an attenuator network upon detection of an individual logic code on a supervisory wavelength.

15. An optical fibre wavelength division multiplex

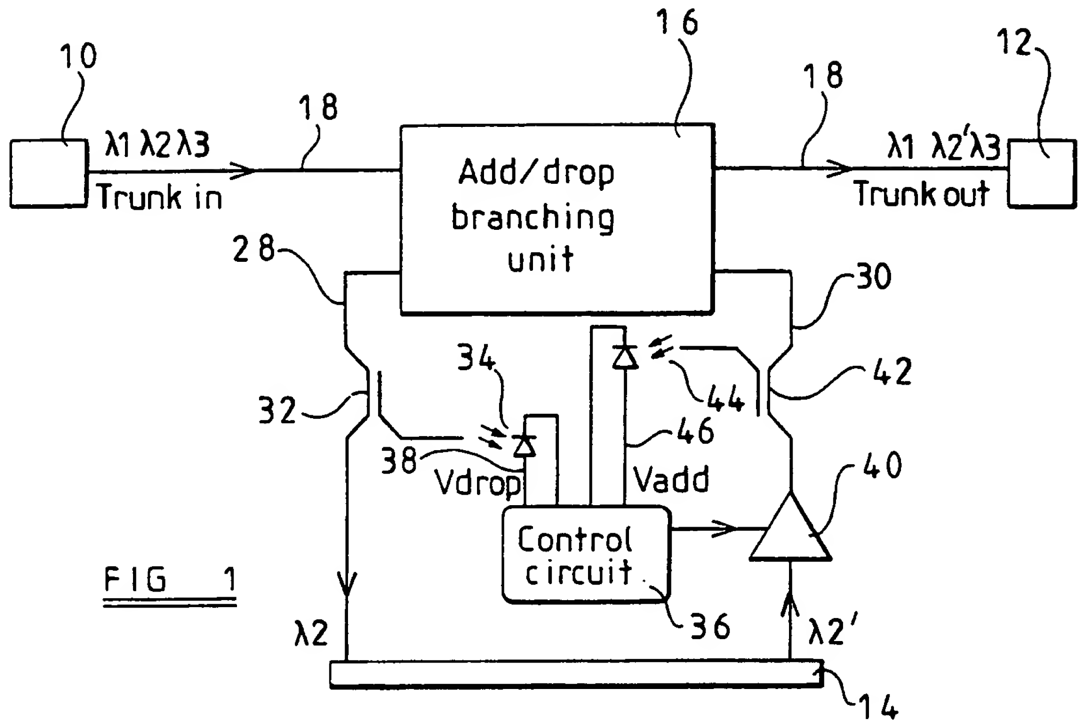
communication system comprising a trunk cable extending between remote transmit/receive stations and provided with at least one branch to another transmit/receive station wherein the or each branch station is adapted to drop one, or more than one predetermined wavelength signal from the trunk onto the branch and to add said predetermined wavelength(s), or predetermined different wavelength(s), from the branch to the trunk, characterised in that the level of the signal(s) dropped from the trunk are sensed and used to adjust to an optimum level the signal(s) added to the trunk.

16. A system as claimed in claim 15, characterised in that a detector is provided at a remote station which detects the presence of signals of said one, or more than one, predetermined wavelength, or predetermined different wavelength(s), and the absence of a signal at any one of these wavelengths routes a supervisory control signal to the branch station in which there is provided an attenuator responsive to the supervisory circuit which reduces the level of the signal(s) added to the trunk.

17. A method of operating an optical fibre wavelength division multiplex communication system in which multiple wavelength signals are transmitted and received along a trunk cable, one, or more than one, predetermined wavelengths are dropped onto a branch to a receive/transmit station and one, or more than one, of said predetermined wavelengths, or predetermined different wavelength(s) is/are added to the trunk, characterised in that the level of the dropped wavelength(s) is/are sensed and used to control the level of the added wavelength(s) which are thereby introduced onto the trunk at an optimum level.

18. A method as claimed in claim 17, characterised in that the absence of one, or more than one, of said

predetermined wavelengths, or said predetermined different wavelengths, at a remote station is detected, a supervisory signal is transmitted from the remote station to the branch and detected at the branch and used to control the attenuation of the added wavelength(s).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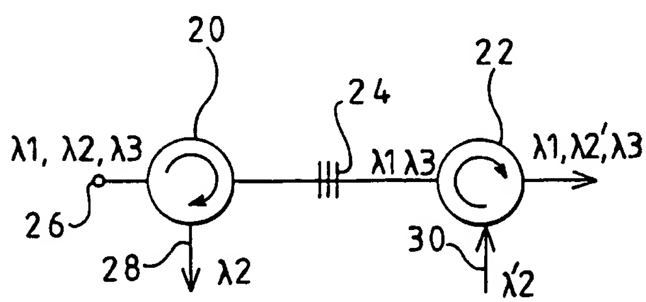
λ1 λ2 λ3
Trunk in
18
16
Add/drop
branching
unit
18
12
λ1 λ2' λ3
Trunk out
28
30
34
32
38
Vdrop
46
Vadd
44
42
40
Control
circuit
36
λ2
λ2'
14

FIG 1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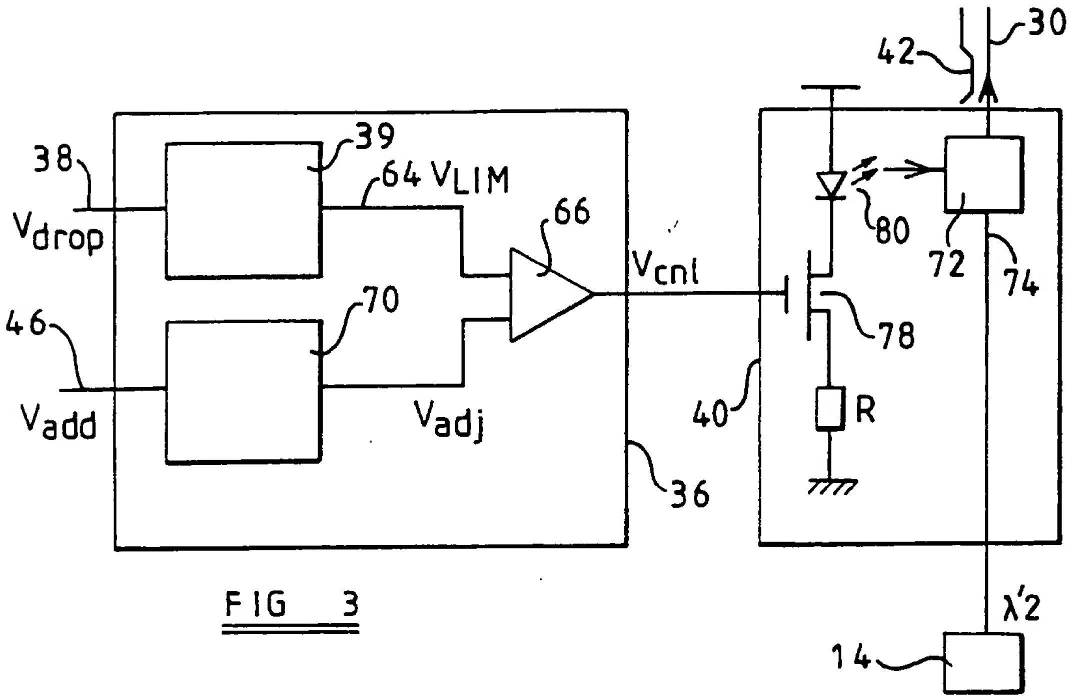
24
λ1, λ2, λ3
λ1 λ3
λ1, λ2', λ3
26
28
λ2
30
λ'2

FIG 2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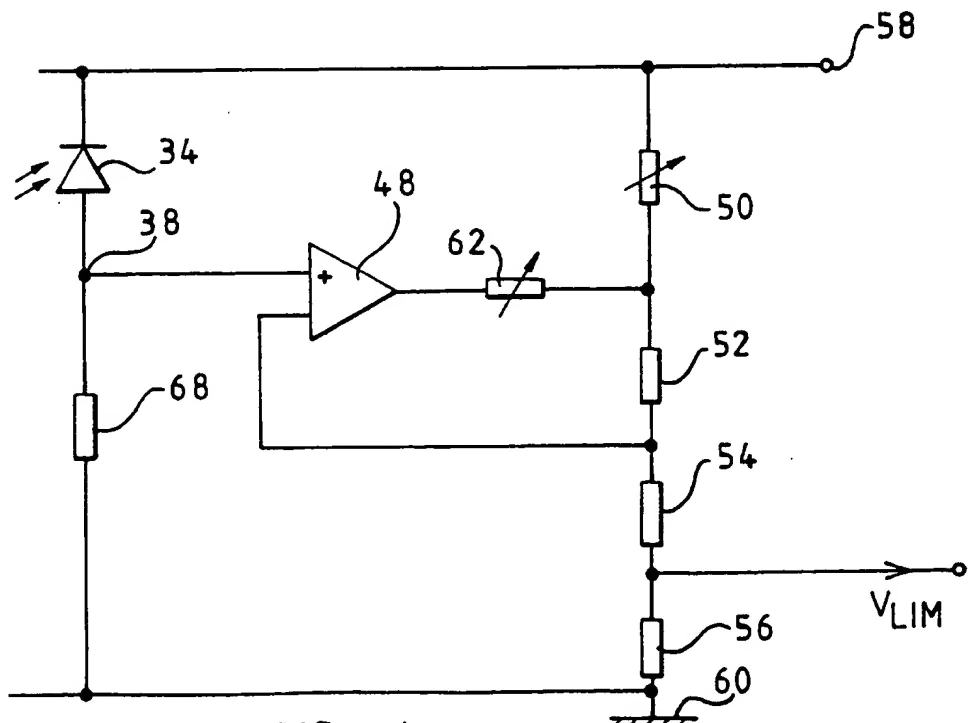
V_{drop}
39
64 V_{LIM}
66
70
46
V_{add}
V_{adj}
V_{cnl}
36
40
42
30
80
72
74
78
R
$\lambda'2$
14

FIG 3


58
34
38
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62
50
52
68
54
V_{LIM}
56
60

FIG 4

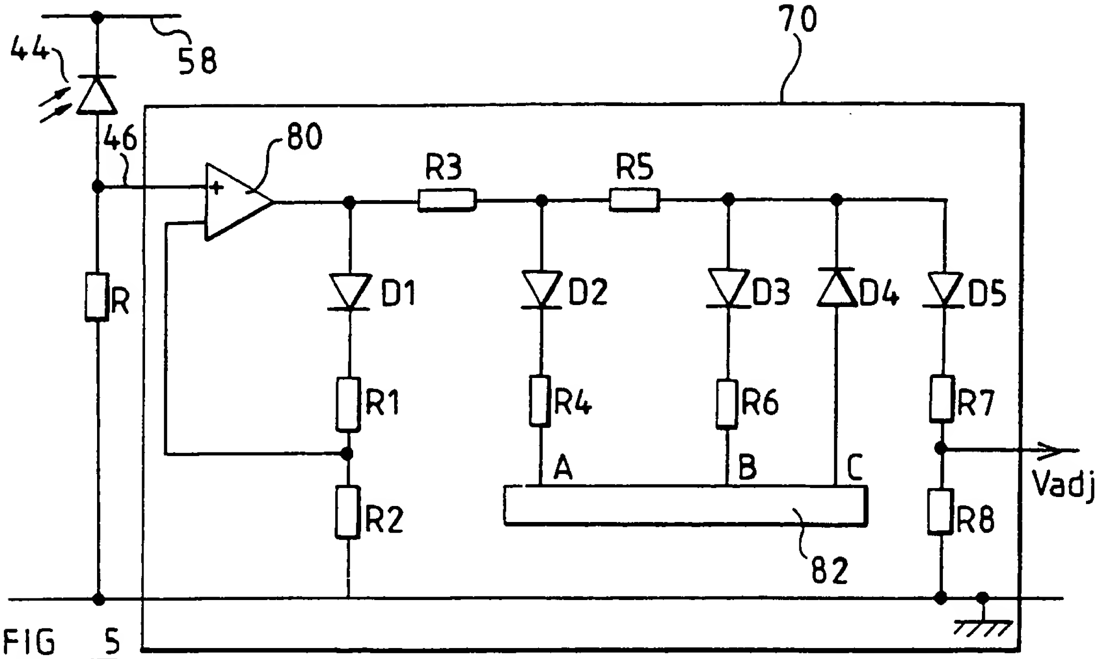

FIG 5

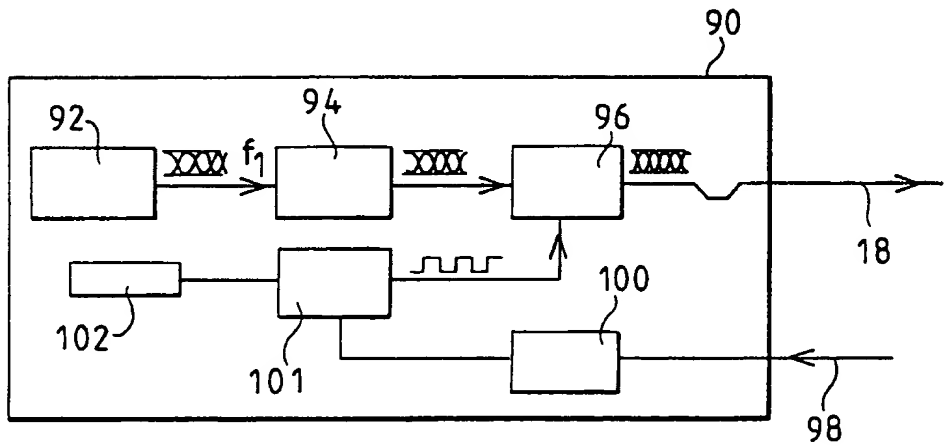

FIG 6

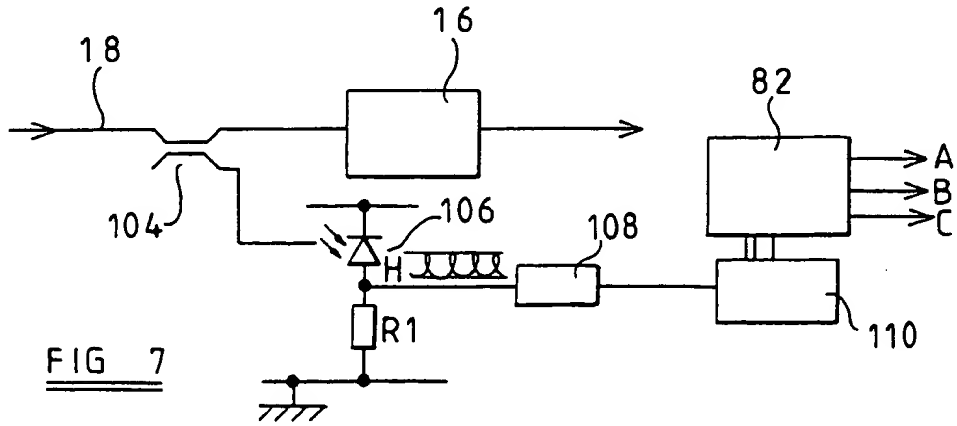

FIG 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/01884

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP,A,0 663 738 (ALCATEL N.V.) 19 July 1995 see column 1, line 15 - line 34 see column 4, line 19 - line 47 see claim 2	1,15,17 2-14,16, 18
X A	EP,A,0 543 570 (AMERICAN TELEPHONE AND TELEGRAPH COMPANY) 26 May 1993	1,15,17 2-14,16, 18
X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 466 (E-1421), 25 August 1993 & JP,A,05 110511 (NEC CORP), 30 April 1993, see abstract	1,15,17

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[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 October 1996	31.10.96

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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